National Neuroscience Institute
SingHealth

Robot for Skull-Base Surgery

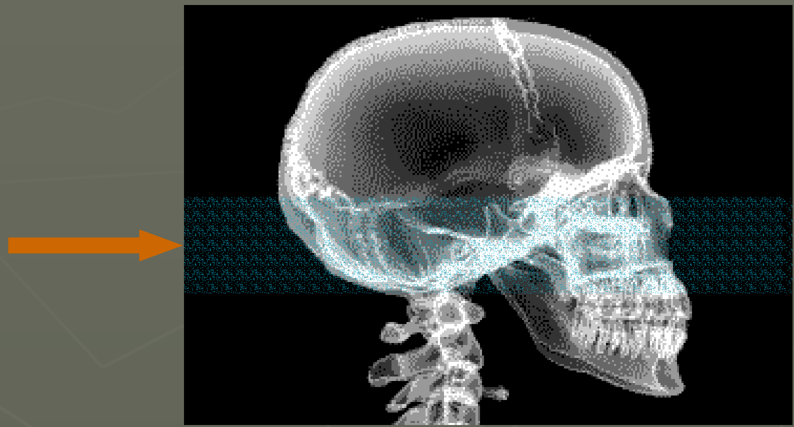
By: Charles Lo Vui Hong

AIMS++
advanced integrated medical systems lab

Neurosurgery

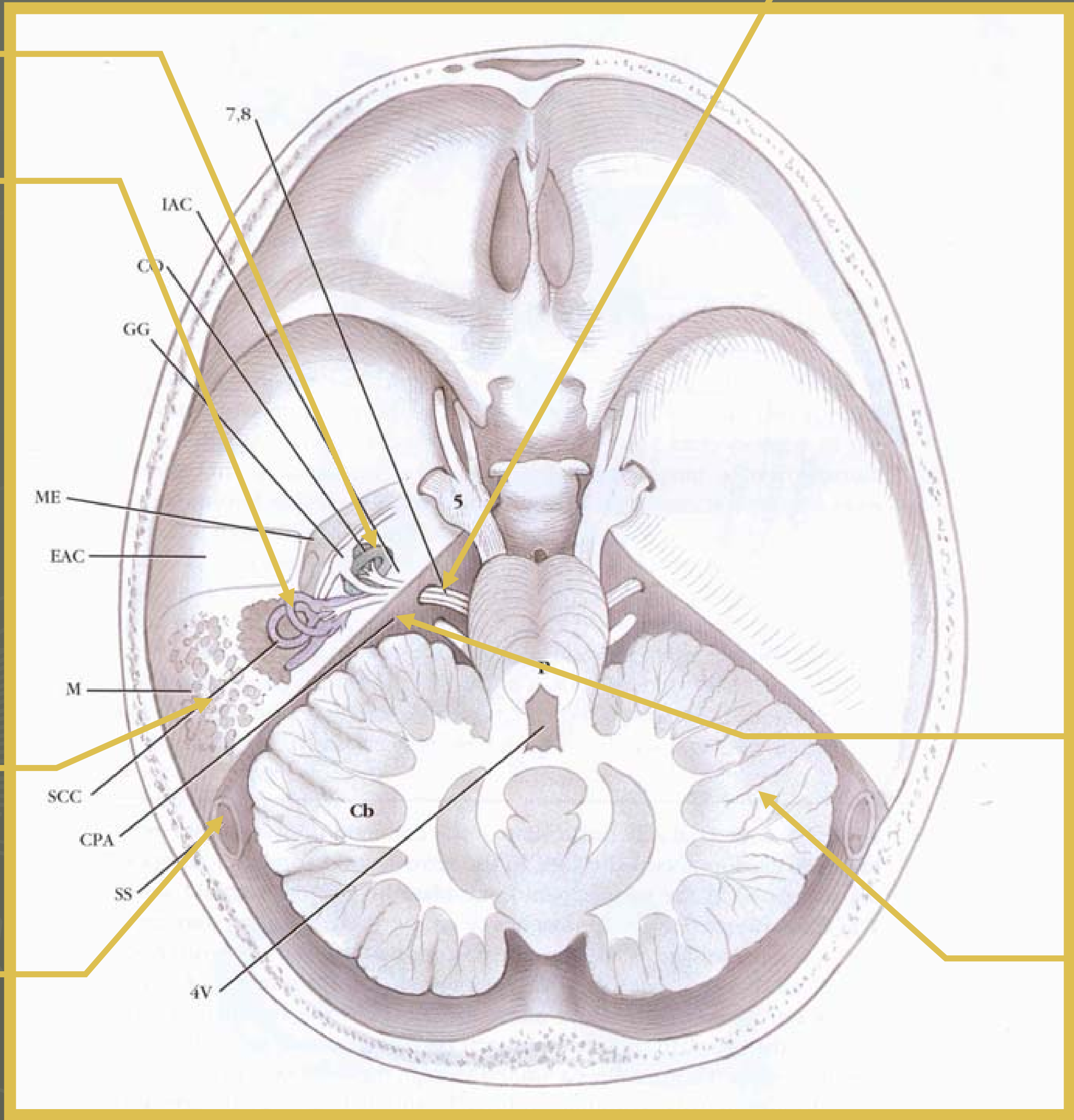
- Commercially available systems (eg.Neuromate, Robodoc, Acrobot) are lacking in the degrees of freedom required for skull base surgery
- Large workspace leads to unconstrained motion that may pose a danger to patient and surgeon

Introduction to Skull Base Surgery

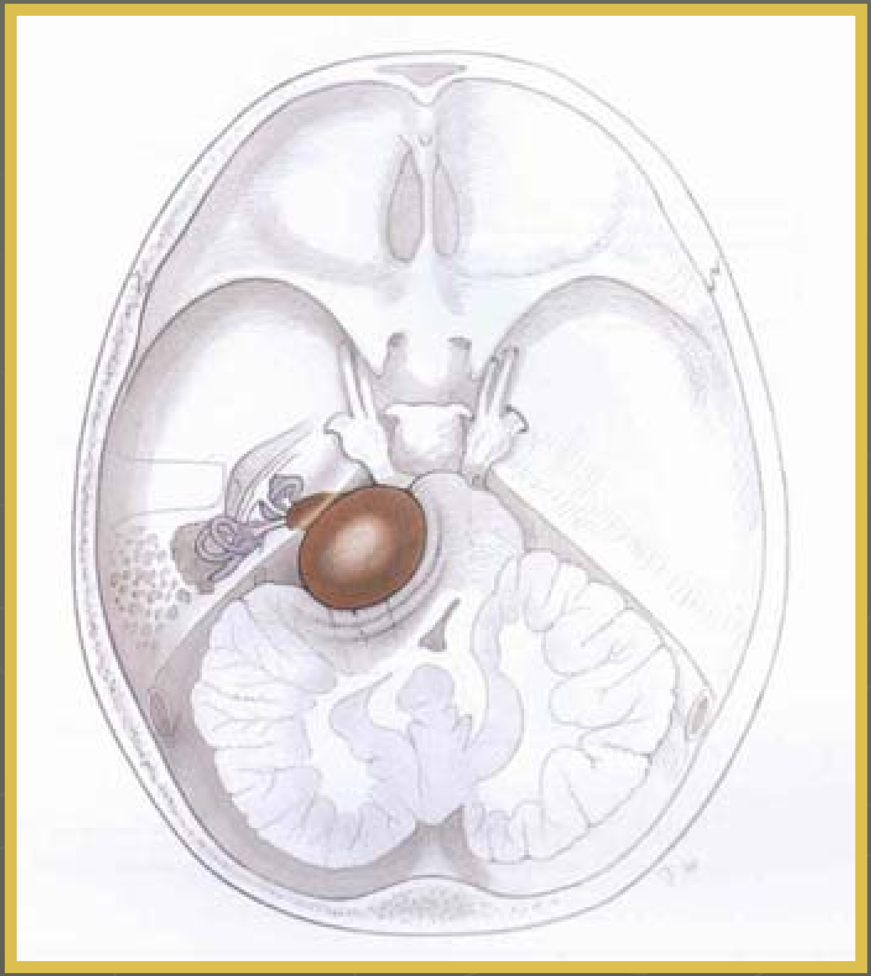


- Involves drilling of the temporal bone
- To access deep seated skull base tumors
- One of the longest operations in neurosurgery(8-13 hours)

Posterior Cranial Fossa



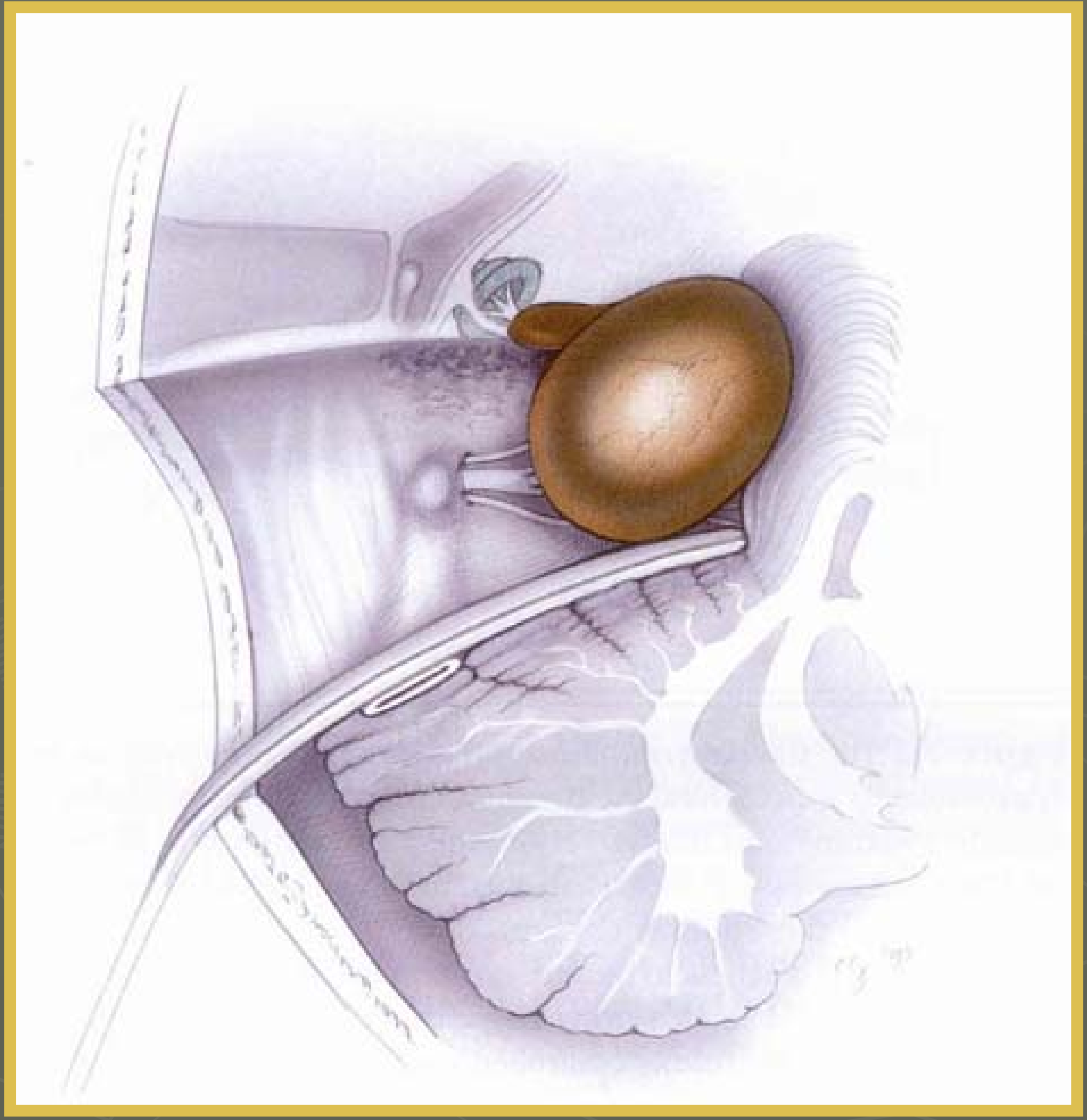
Acoustic Neuromas



Medium-sized Acoustic Neuroma

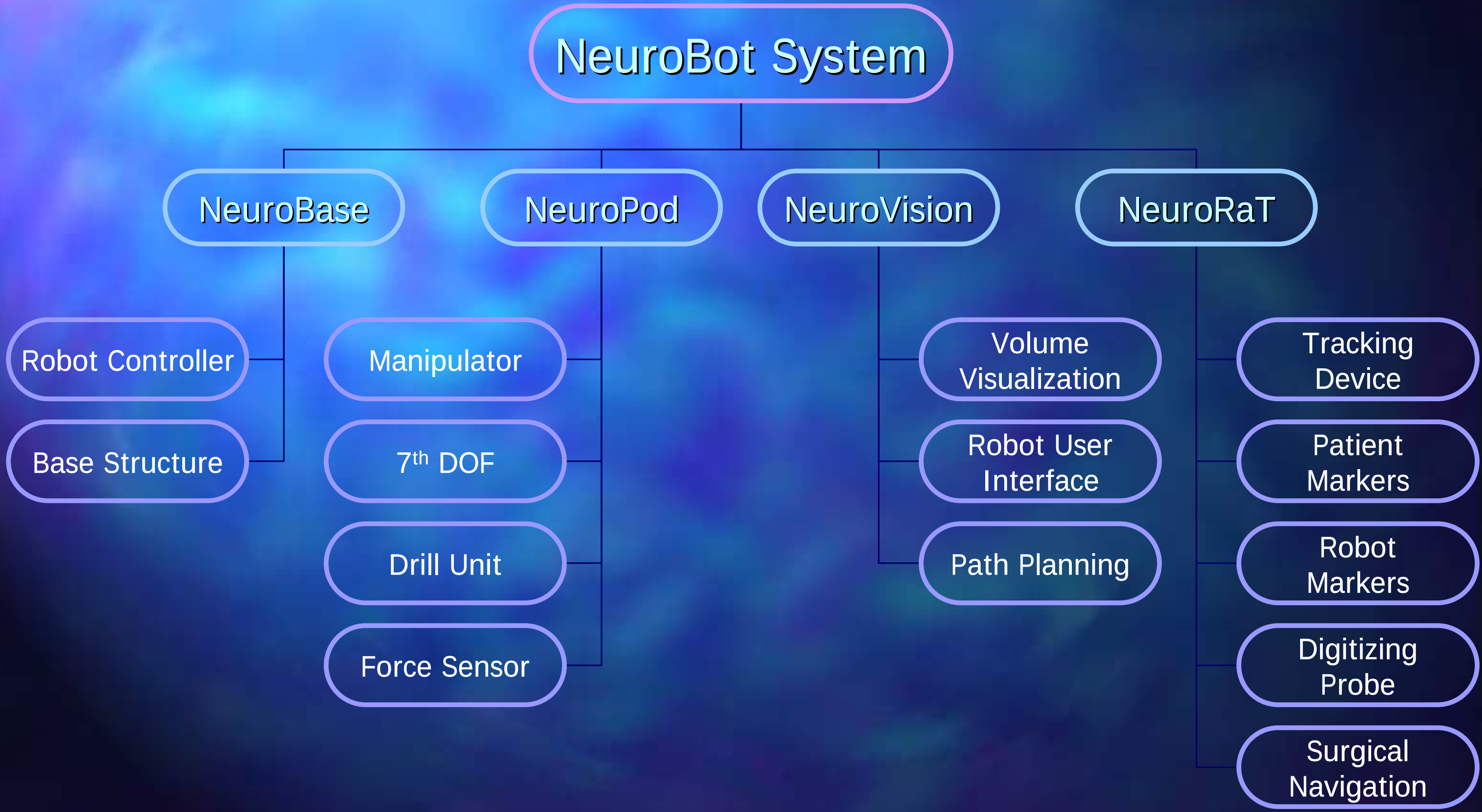
Common Surgical Approaches

Translabyrinthine Approach

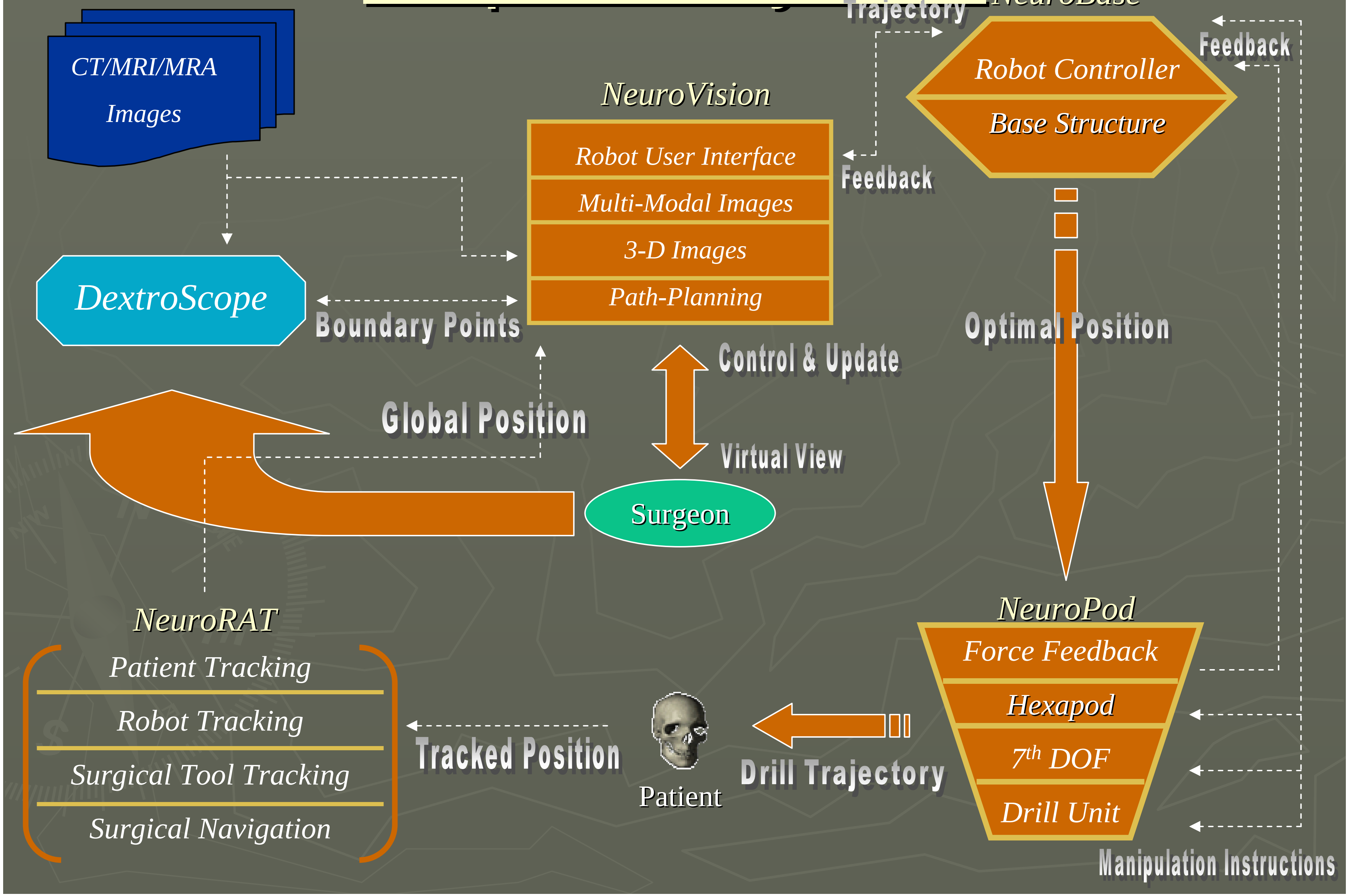


Skull Base Surgery

System Modules

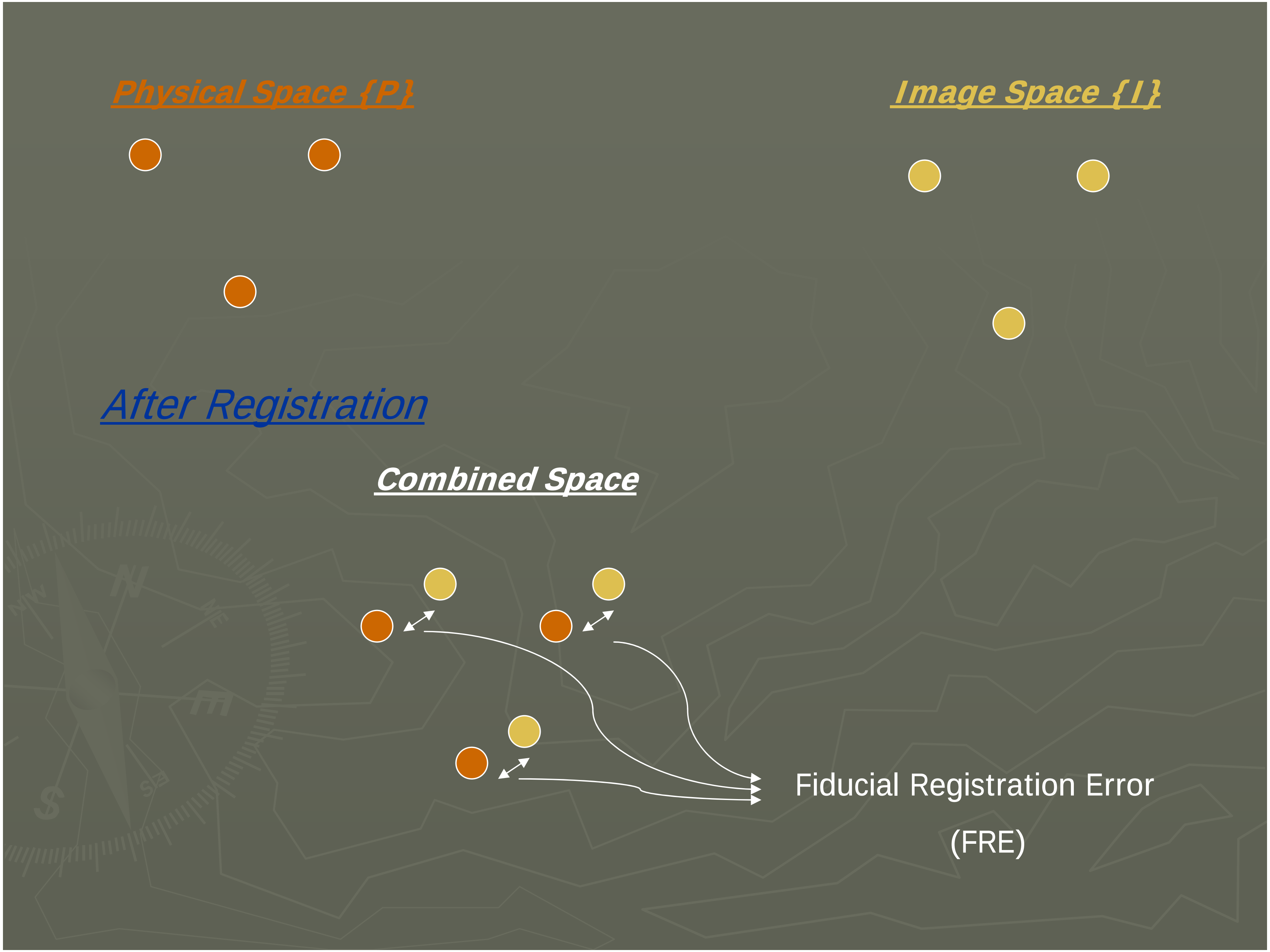


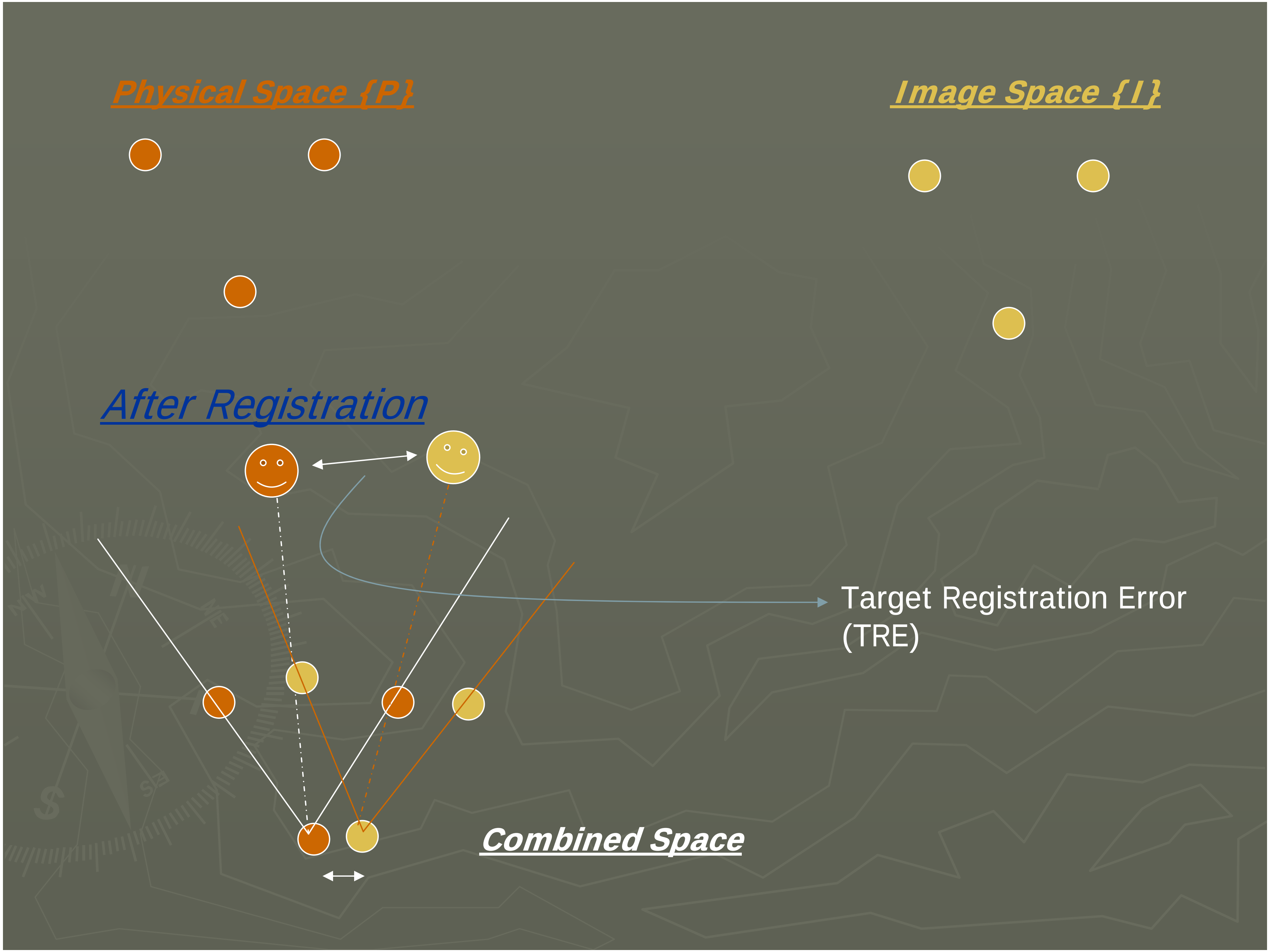
Proposed System



Registration Errors

"During patient registration, surgeons strive to minimize a number provided as feedback by the registration system. Unfortunately, this measure of error is merely an estimate of the accuracy of the rigid body transformation. This estimate informs the operator only of error in the geometric alignment of the fiducial markers registered. Reliance on this number as a proxy for the accuracy of the computer-assisted navigation during sugery is naïve at best. At worst, the values may be misleading, especially with respect to the target registration error (TRE) which is of paramount importance clinically."

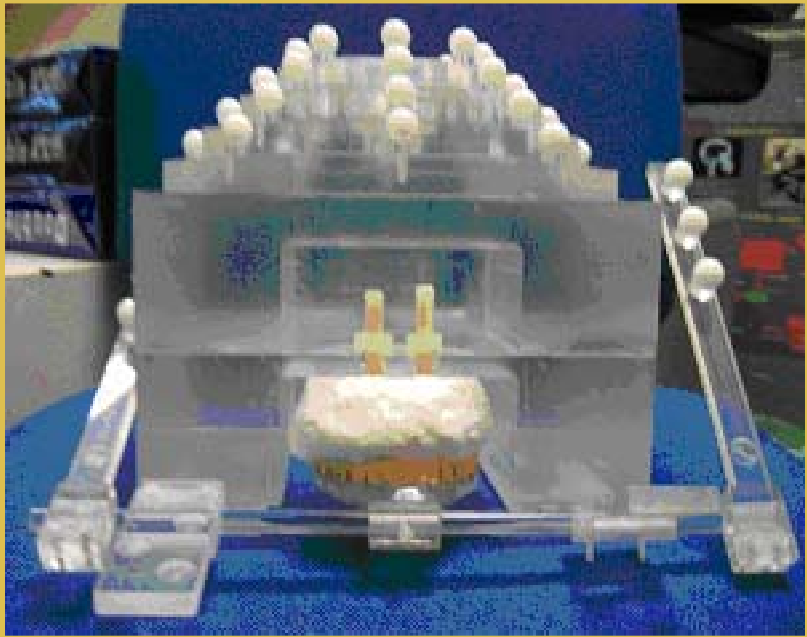

Physical Space {P}
Image Space {I}
After Registration
Combined Space
Fiducial Registration Error
(FRE)


Physical Space {P}
Image Space {I}
After Registration
Target Registration Error
(TRE)
Combined Space

NeuroRAT

Sub-Module:

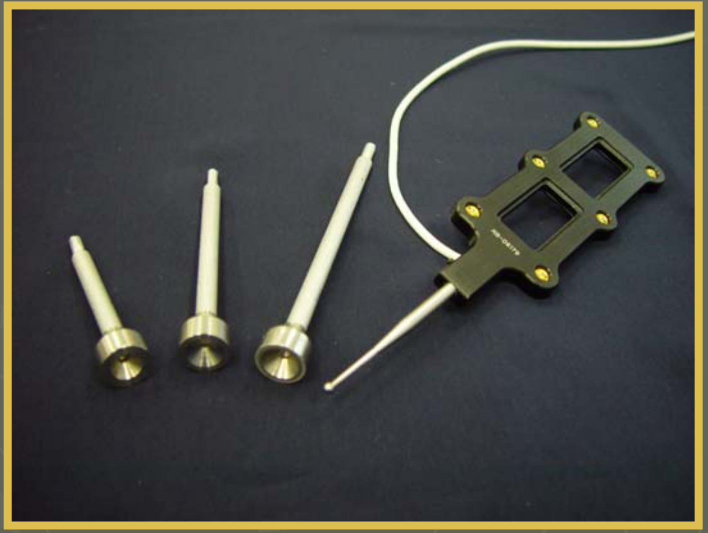
Patient Markers

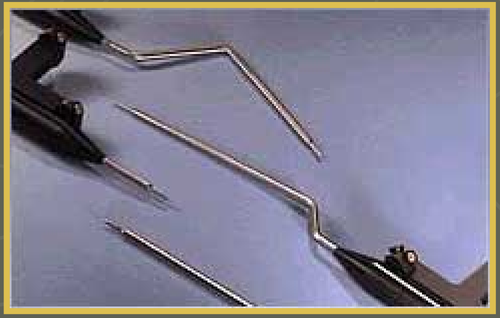


NeuroRAT

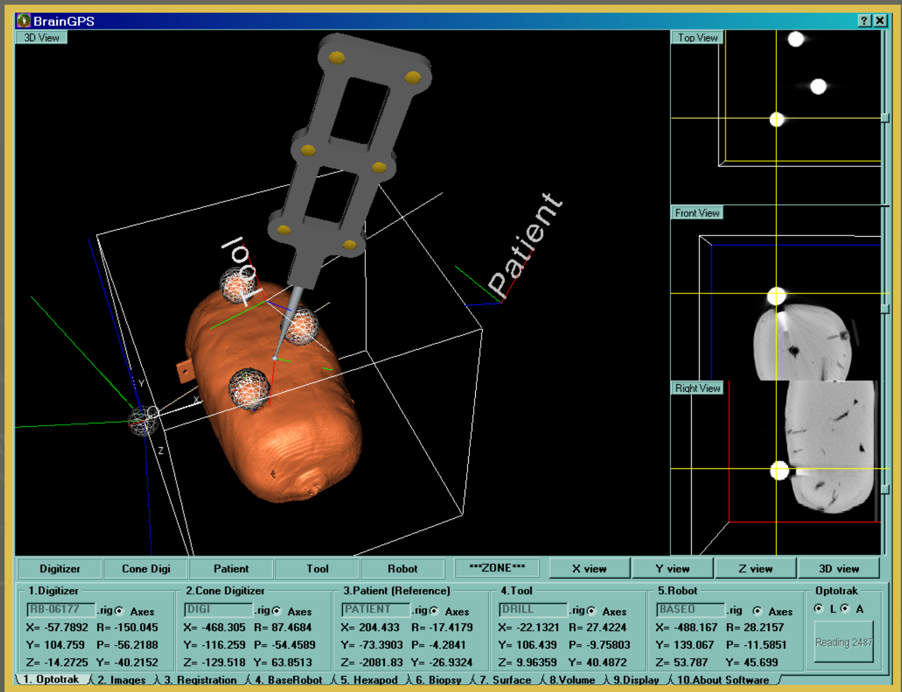
<u>Sub-Module:</u>

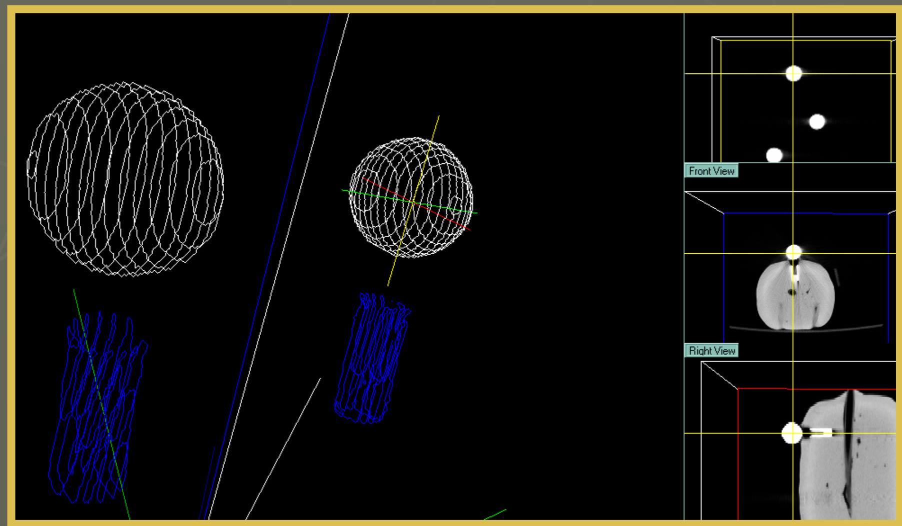
Digitizing Probe





NeuroRAT

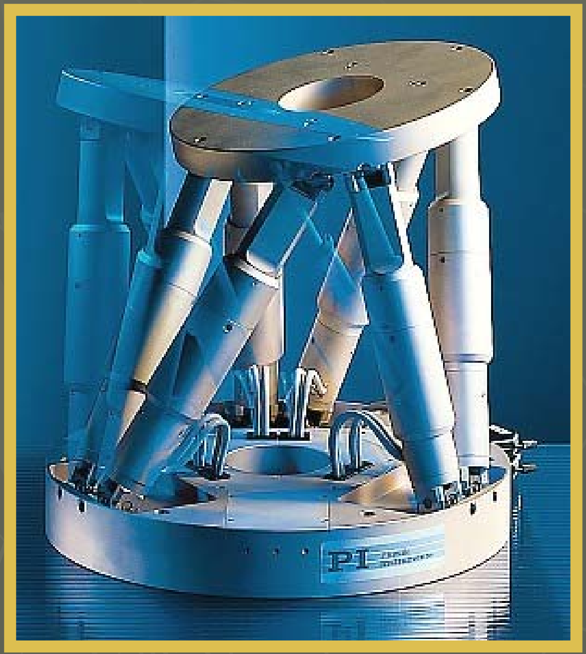

BrainGPS
3D View
Top View
Front View
Right View
Tool
Patient
Digitizer
Cone Digi
Patient
Tool
Robot
ZONE
X view
Y view
Z view
3D view
1.Digitizer
RB-06177 .rig Axes
X= -57.7892 R= -150.045
Y= 104.759 P= -56.2188
Z= -14.2725 Y= -40.2152
2.Cone Digitizer
DIGI .rig Axes
X= -468.305 R= 87.4684
Y= -116.259 P= -54.4589
Z= -129.518 Y= 63.8513
3.Patient (Reference)
PATIENT .rig Axes
X= 204.433 R= -17.4179
Y= -73.3903 P= -4.2841
Z= -2081.83 Y= -26.9324
4.Tool
DRILL .rig Axes
X= -22.1321 R= 27.4224
Y= 106.439 P= -9.75803
Z= 9.96359 Y= 40.4872
5.Robot
BASE0 .rig Axes
X= -488.167 R= 28.2157
Y= 139.067 P= -11.5851
Z= 53.787 Y= 45.699
Optotrak
L A
Reading 2487
1. Optotrak
2. Images
3. Registration
4. BaseRobot
5. Hexapod
6. Biopsy
7. Surface
8.Volume
9.Display
10.About Software


Front View
Right View

NeuroPod

Sub-Module:

Manipulator



Description:

6 axis parallel kinematic robot (Hexapod)

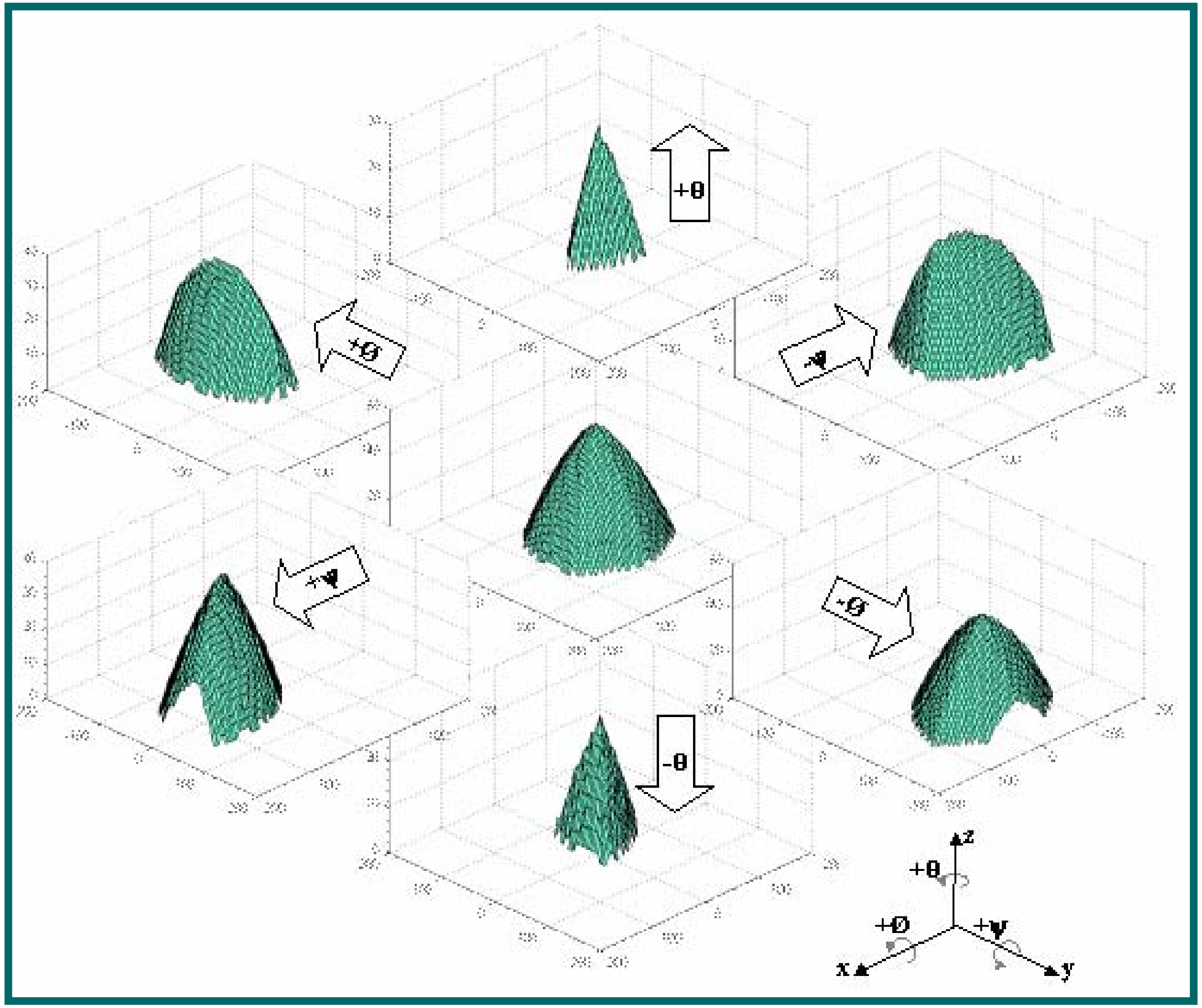
- micron resolution
- small workspace
- high stiffness

(Fraunhofer-Institut Produktionstechnick and Automatisierung)

Function:

To move drill unit along a specified drill trajectory

Workspace Analysis



Workspace Analysis

x-axis = $[\phi_{min}, \phi_{max}]$

y-axis = $[\theta_{min}, \theta_{max}]$

z-axis = $[\psi_{min}, \psi_{max}]$

$$G = \begin{bmatrix} \phi_{min} & \theta_{min} & \psi_{min} \\ \phi_{min} & \theta_{min} & \psi_{max} \\ \phi_{min} & \theta_{max} & \psi_{min} \\ \phi_{min} & \theta_{max} & \psi_{max} \\ \phi_{max} & \theta_{min} & \psi_{min} \\ \phi_{max} & \theta_{min} & \psi_{max} \\ \phi_{max} & \theta_{max} & \psi_{min} \\ \phi_{max} & \theta_{max} & \psi_{max} \end{bmatrix}$$

Iteration 1

Iteration 2

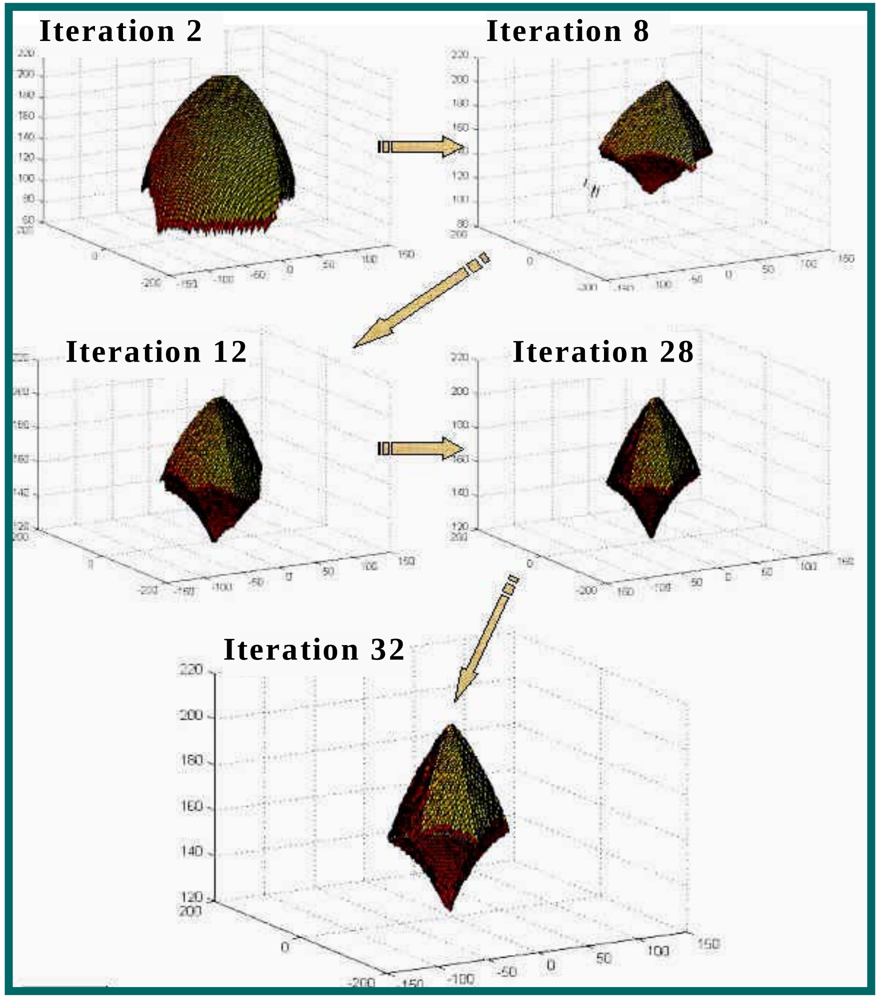
Iteration 7

x-axis = $\left[\phi_{min}, \frac{\phi_{max} + \phi_{min}}{2}, \phi_{max}\right]$

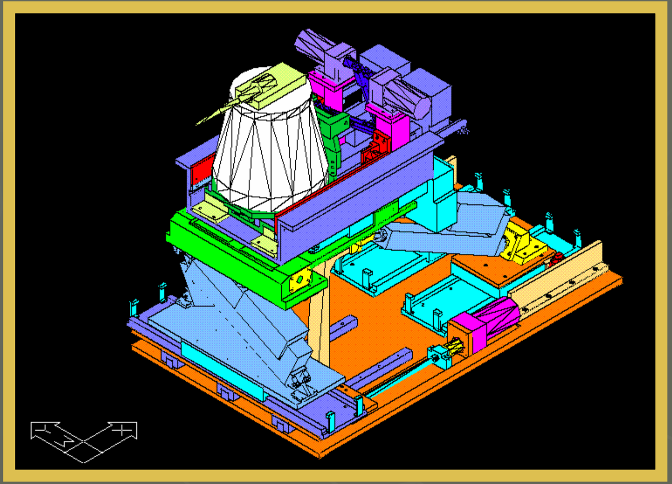
y-axis = $\left[\theta_{min}, \frac{\theta_{max} + \theta_{min}}{2}, \theta_{max}\right]$

z-axis = $\left[\psi_{min}, \frac{\psi_{axx} + \psi_{min}}{2}, \psi_{max}\right]$

Workspace Analysis



NeuroBase – 1st Prototype



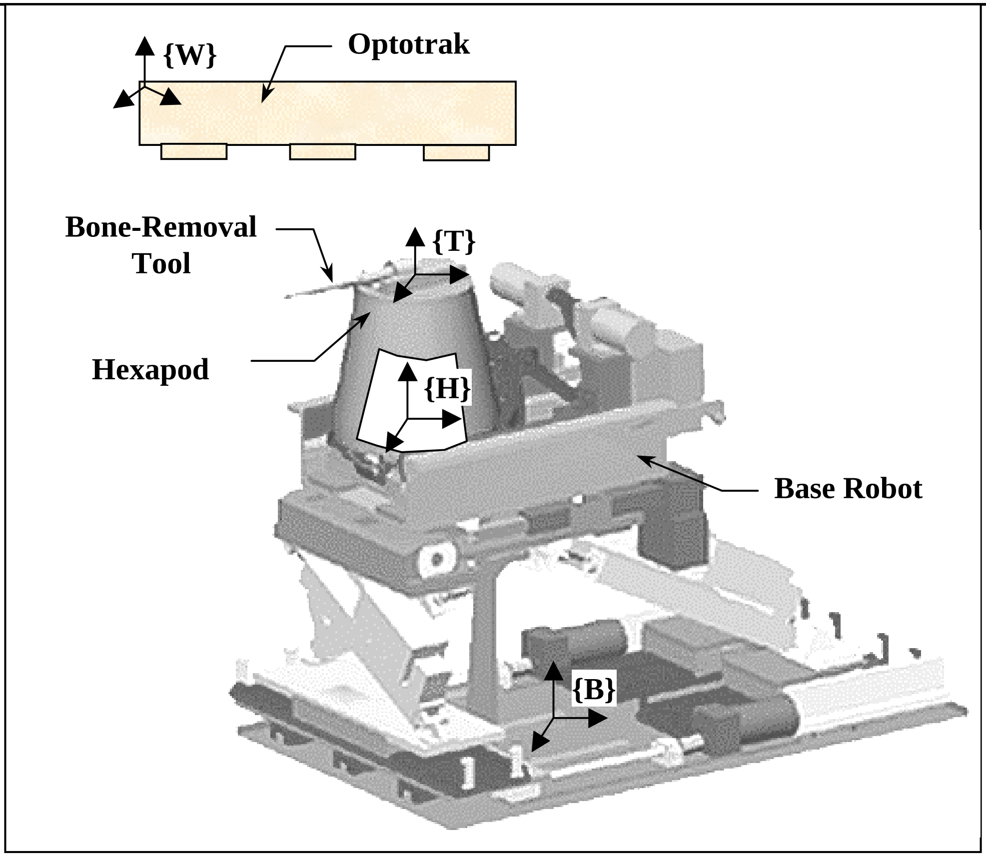
Description:

Hybrid parallel serial system with decoupled motions

Function:

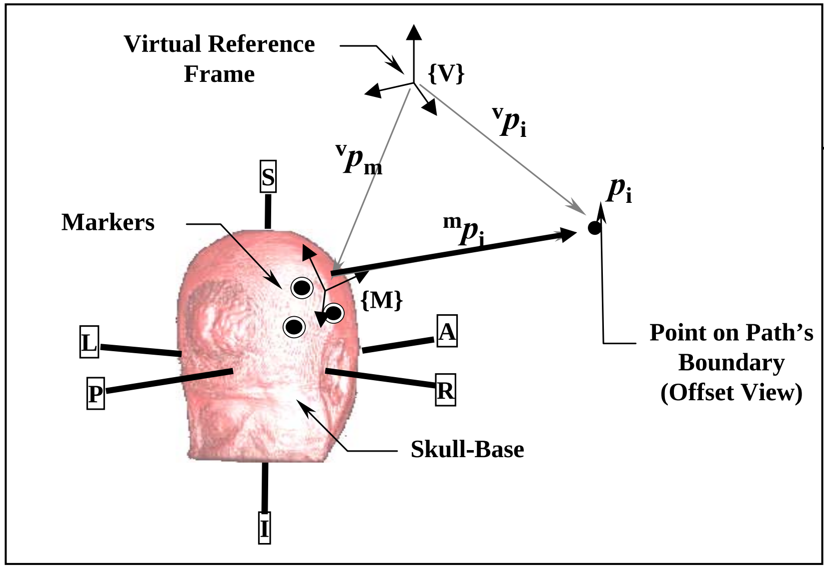
To place NeuroPod *rigidly* in optimum working volume to maximize use of Hexapod's workspace

Robot Registration



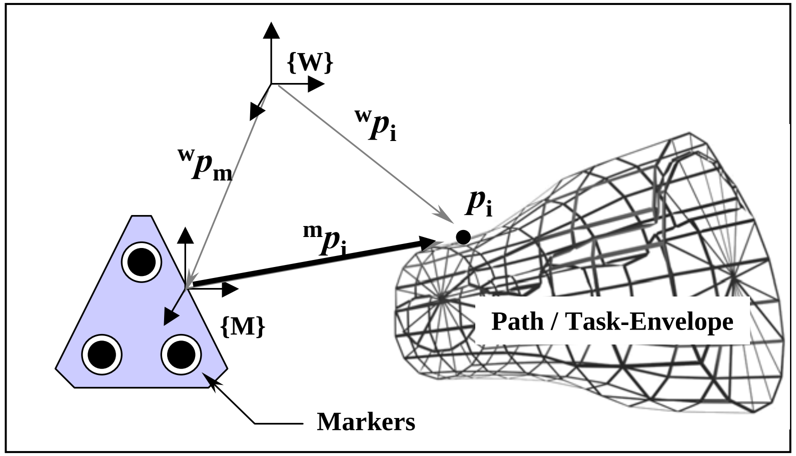
$$A = Rp$$

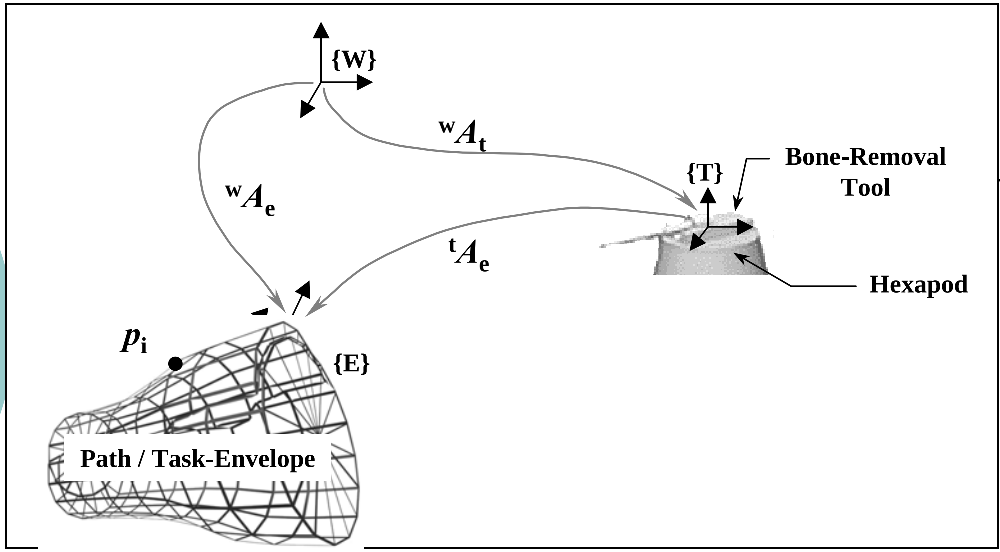
$$^{b}A_{t} = {^{b}A_{h}}\, {^{h}A_{t}}$$



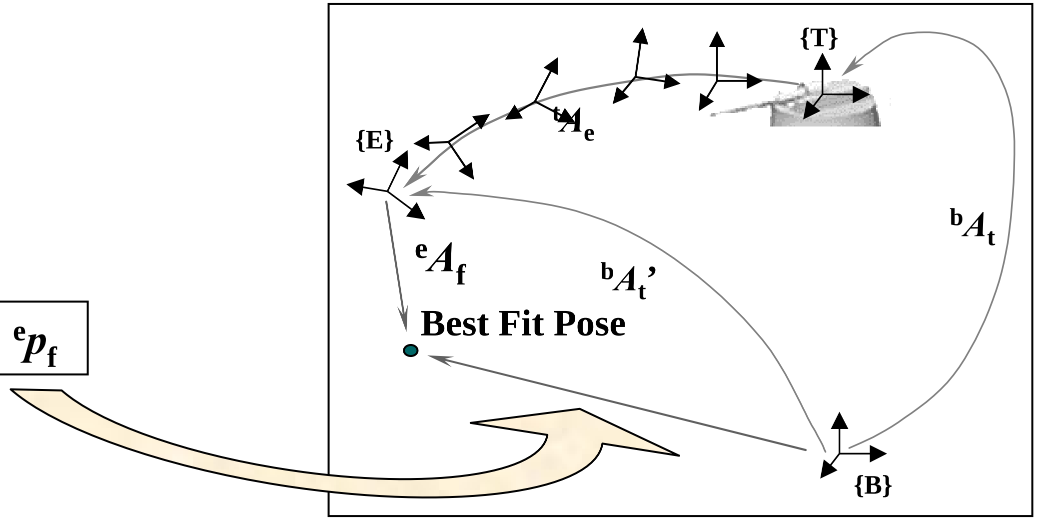
$$^{m}\boldsymbol{P}_{e} = {}^{v}\boldsymbol{P}_{e} - {}^{v}\boldsymbol{p}_{m}$$

where $\boldsymbol{P} = [\boldsymbol{p}_{i}, \boldsymbol{p}_{i+1}, \ldots, \boldsymbol{p}_{n}]^{T}$





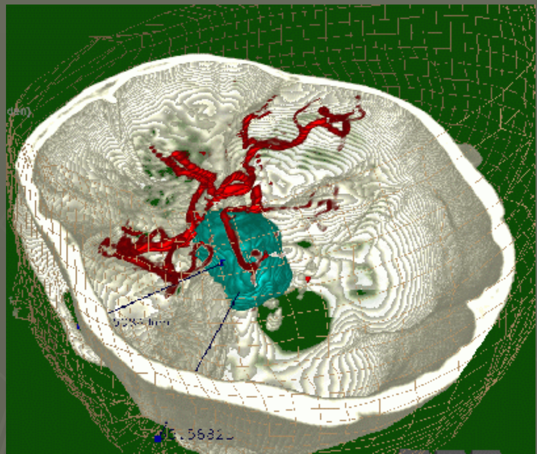
$${}^{b}R_{t}' \quad {}^{e}R_{f} \quad {}^{b}p_{t}' \quad {}^{e}p_{f}$$

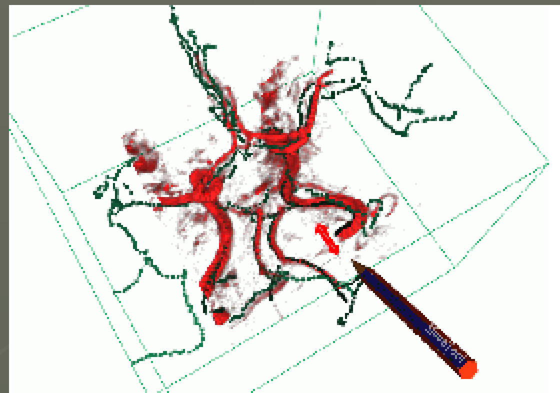


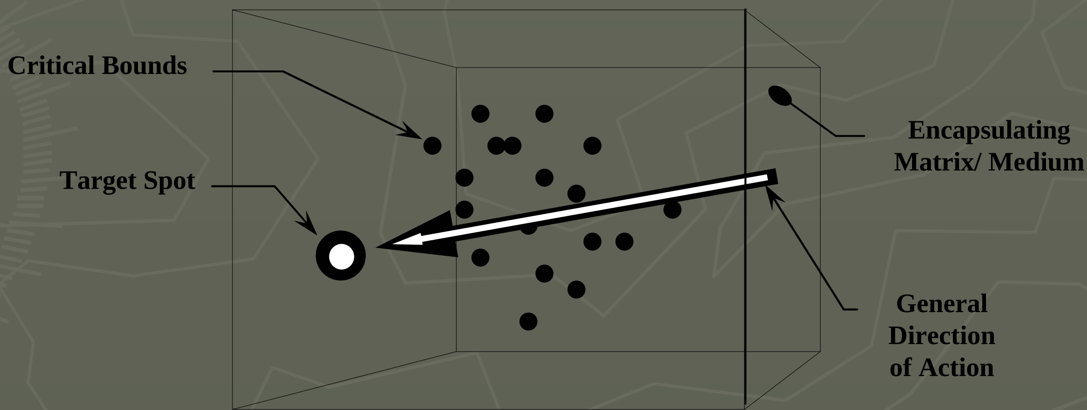
Sub-Module: Path Planning

Manual (Dextrascope)

<u>CONSTRAINT TASK-ENVELOPE CONSTRUCTION (*CONTEC*)</u>



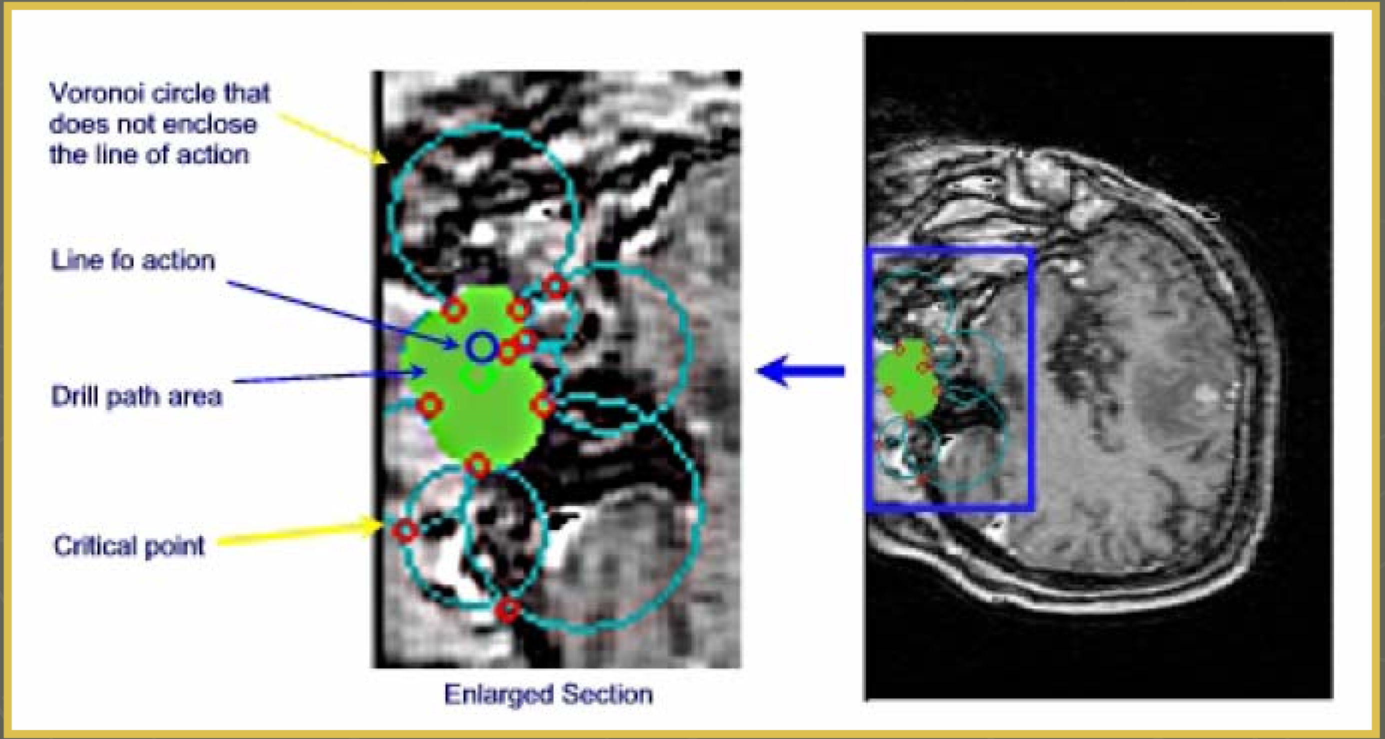




Problem Formulation and Representation

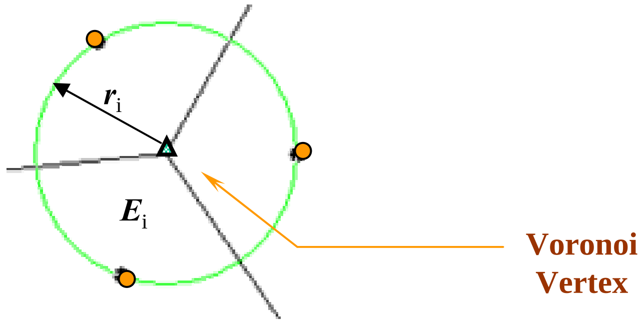
Sub-Module: Path Planning

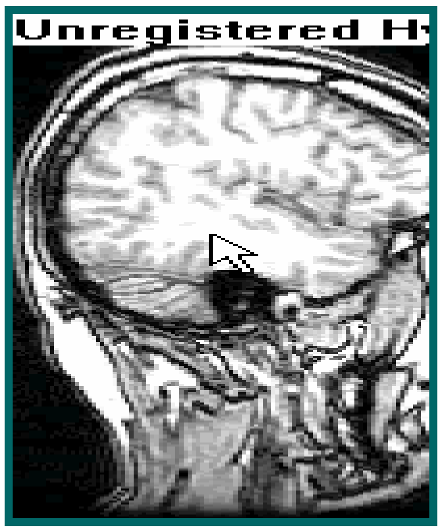
Automatic (CONTEC)

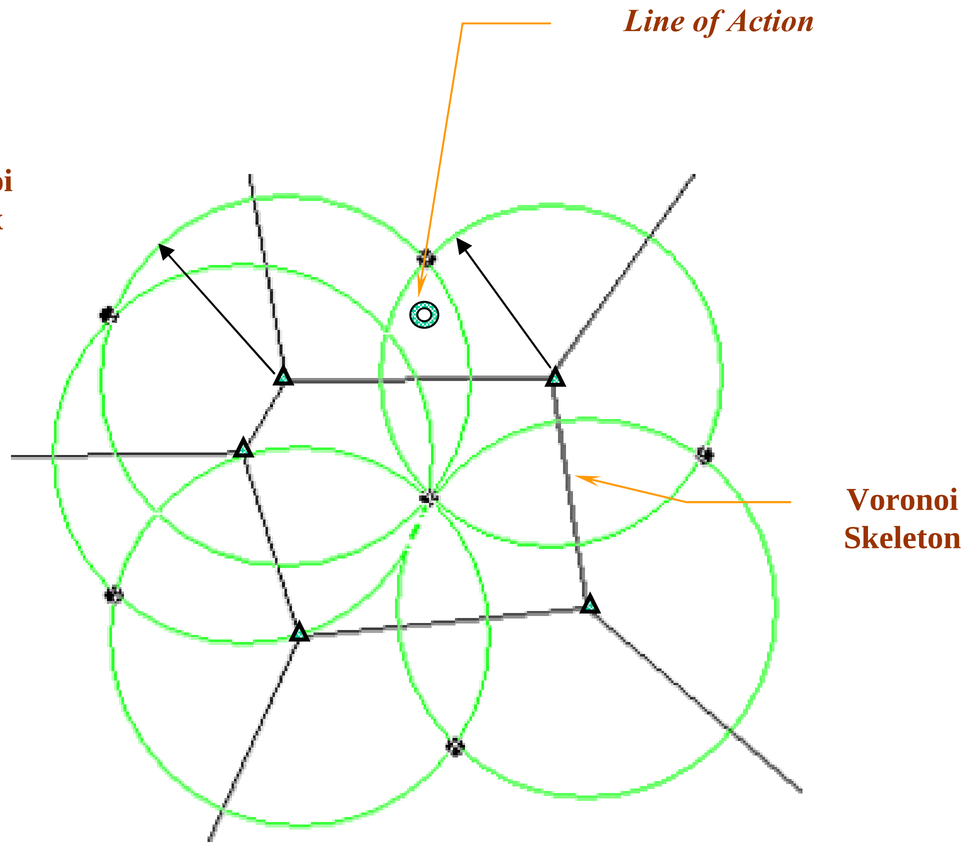


Sub-Module: Path Planning (1)

CONTEC

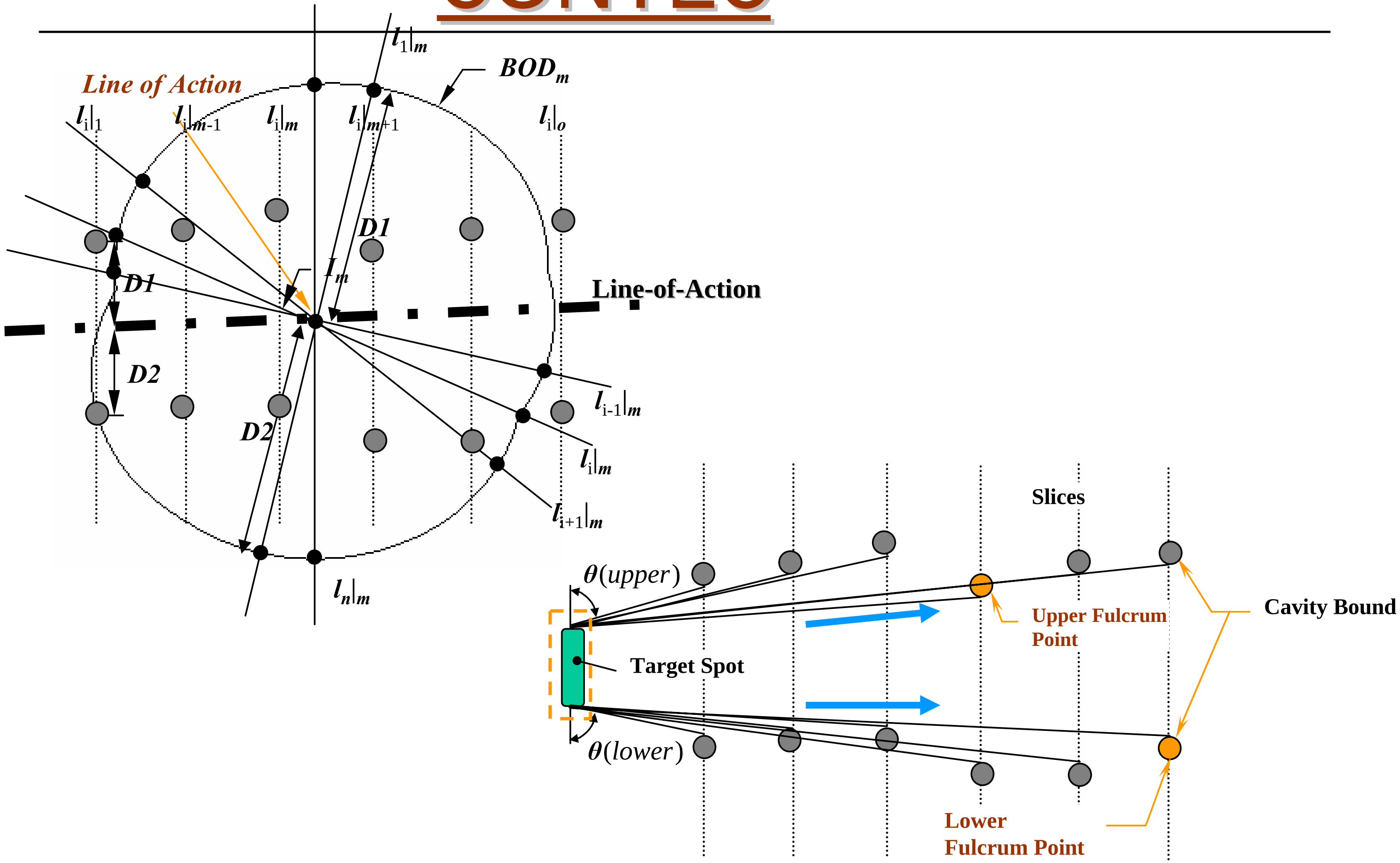






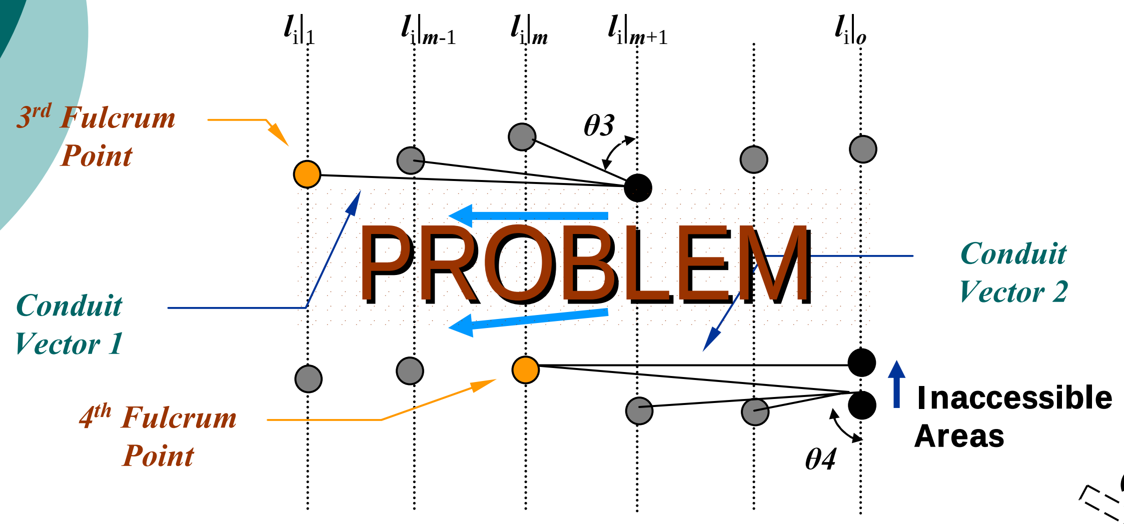
Sub-Module: Path Planning (1)

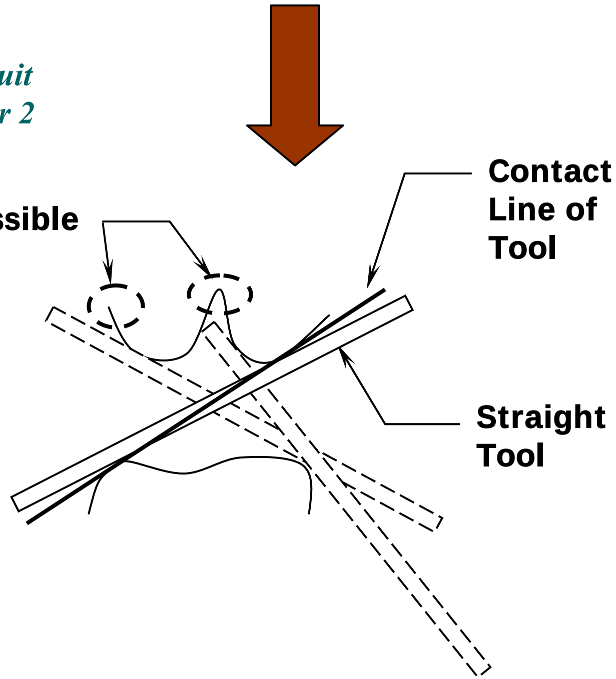
CONTEC



Sub-Module: Path Planning (1)

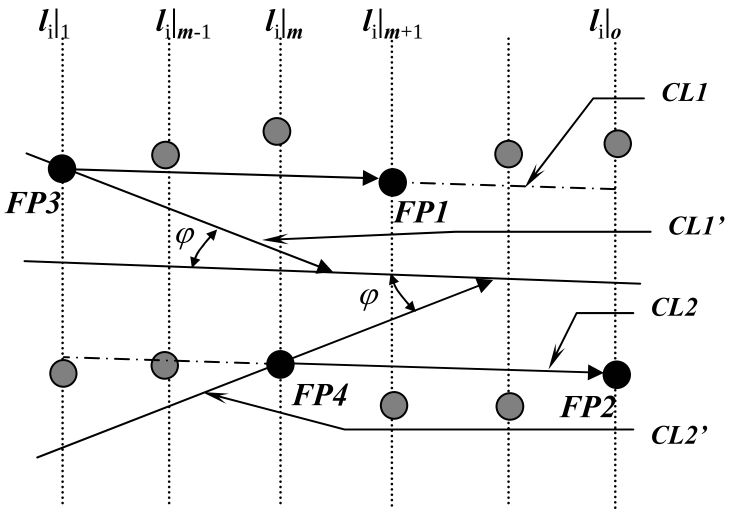
CONTEC



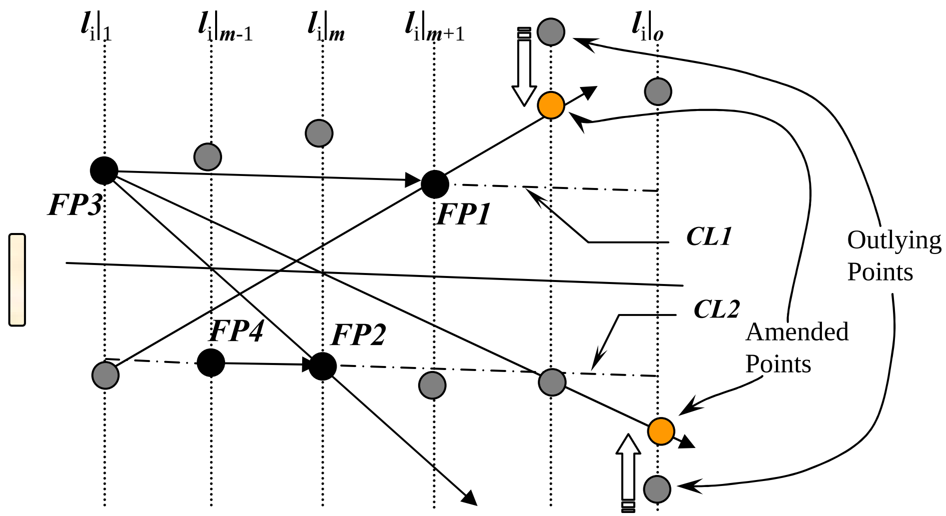


Sub-Module: Path Planning (1)

CONTEC

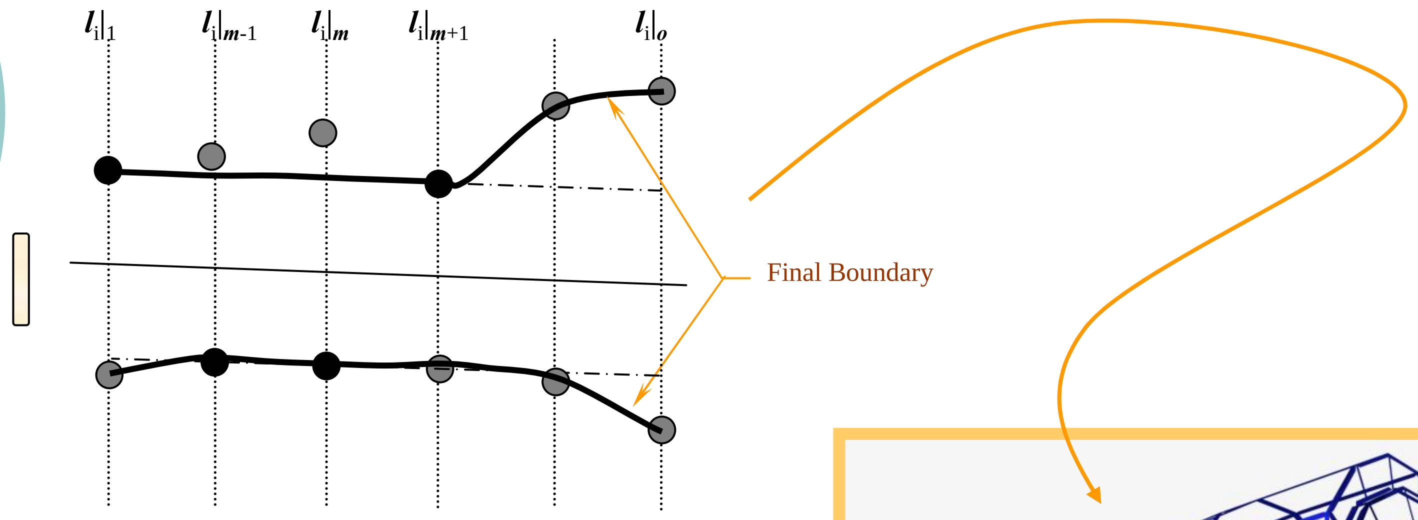


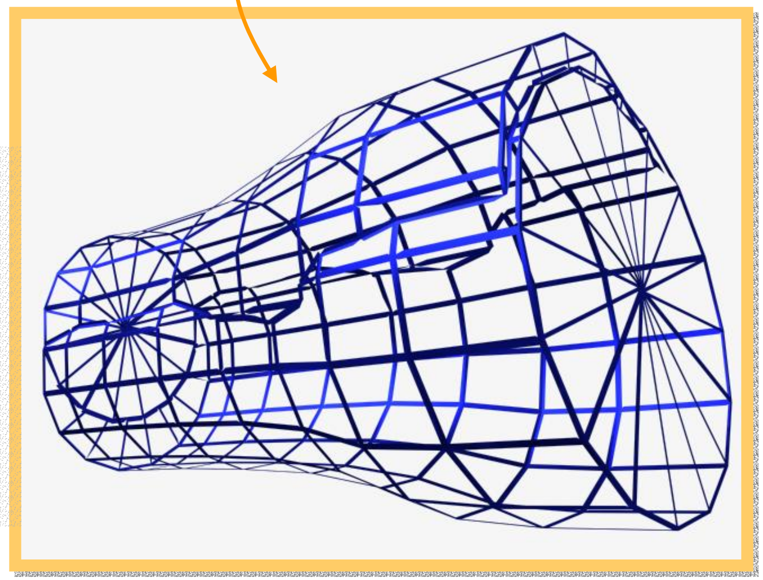
$$\varphi = \min\left(\|\phi_{min}\|, \ \|\phi_{max}\|, \ \|\theta_{min}\|, \ \|\theta_{max}\|, \ \|\psi_{min}\|, \ \|\psi_{max}\| \right)$$



Sub-Module: Path Planning (1)

CONTEC



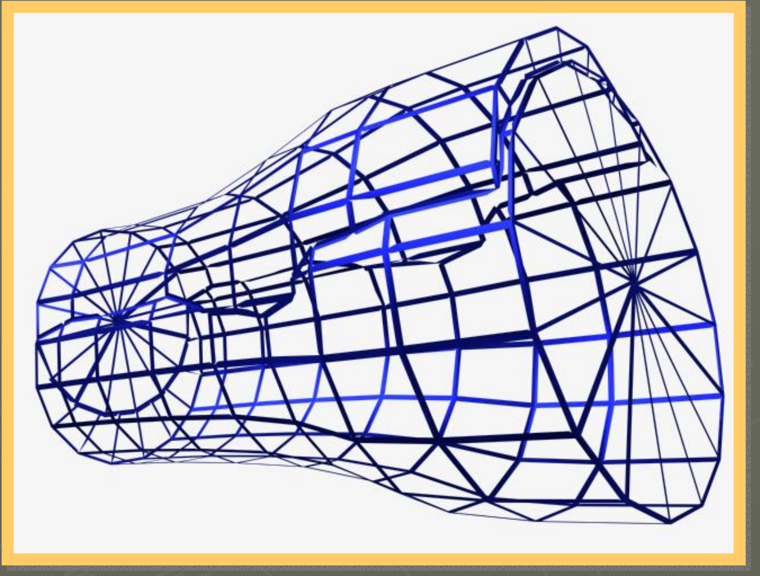


Four main properties are inherent for the constructed conduit:

- It avoids all critical areas/bounds;
- Allows for maximal line of sight;
- Alleviates areas which are inaccessible;
- Takes into account the rotational ability of the parallel manipulator.

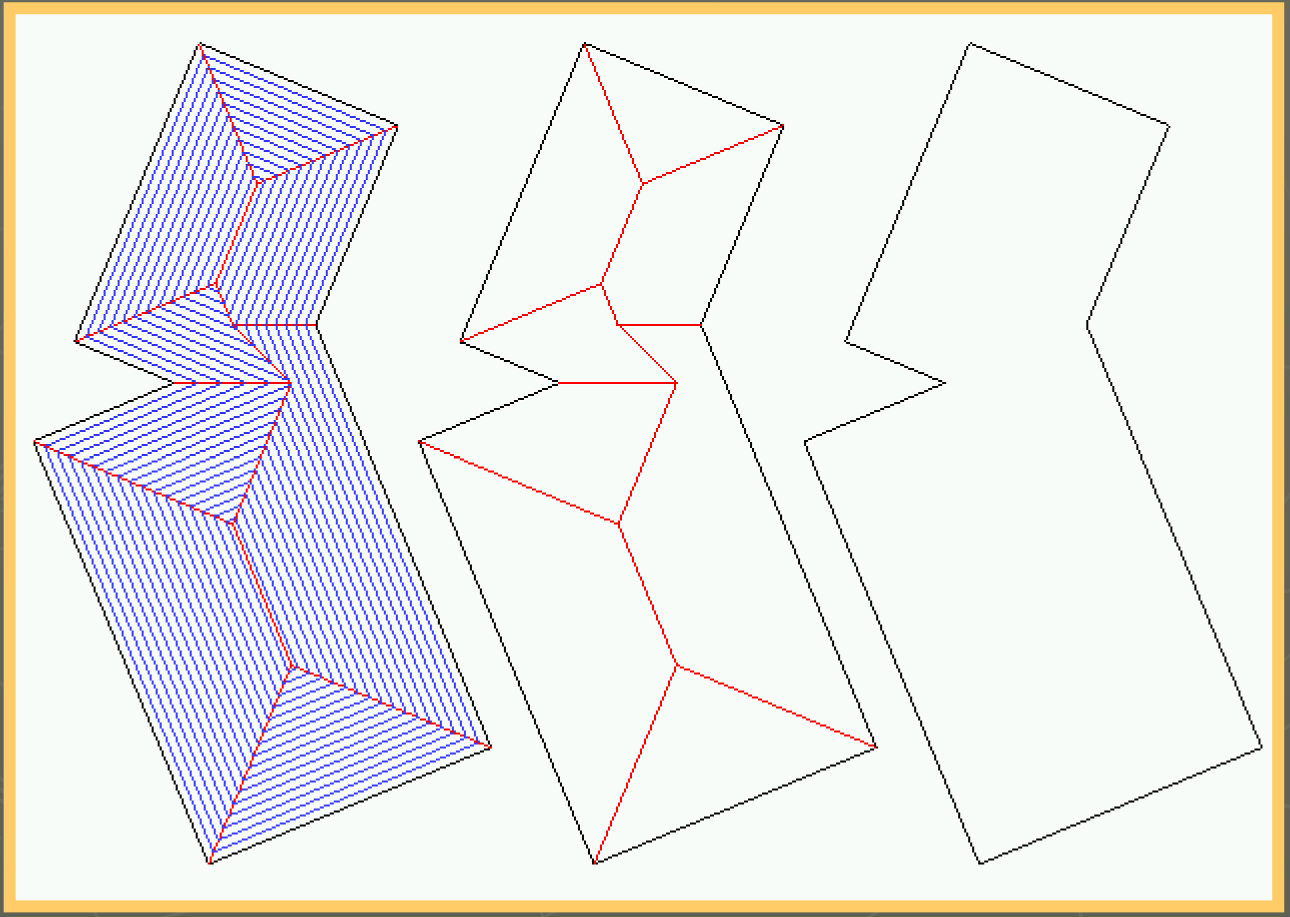
Sub-Module: Path Planning (2)

ABNO



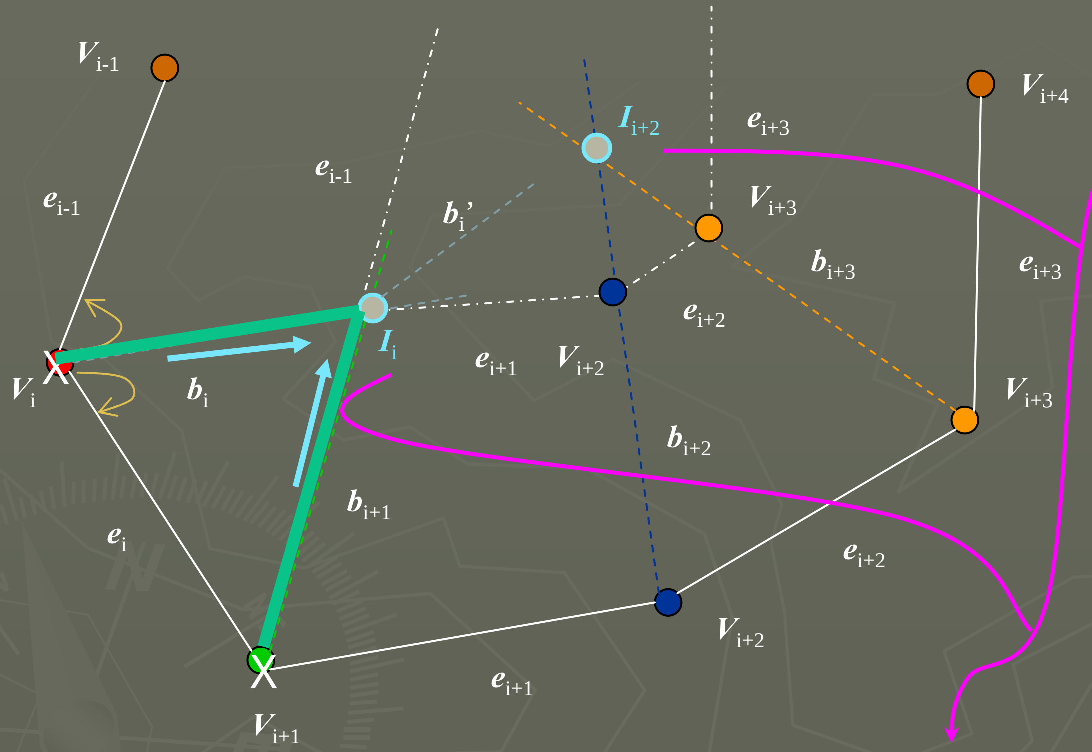
Sub-Module: Path Planning (2)

ABNO



Sub-Module: Path Planning (2)

ABNO



List of Active Vertices

LAV_1	LAV_2
$V_1 \to e_n, e_1\ (b_1)$	$V_1 \to e_n, e_1\ (b_1)$
.	.
.	.
$V_{i-1} \to e_{i-2}, e_{i-1}\ (b_{i-1})$	$V_{i-1} \to e_{i-2}, e_{i-1}\ (b_{i-1})$
$V_i \to e_{i-1}, e_i\ (b_i)$	$I_i \to e_{i-1}, e_{i+1}\ (b_i')$
$V_{i+1} \to e_i, e_{i+1}\ (b_{i+1})$	
.	.
.	.
$V_n \to e_{n-1}, e_n\ (b_n)$	$V_n \to e_{n-1}, e_n\ (b_n)$

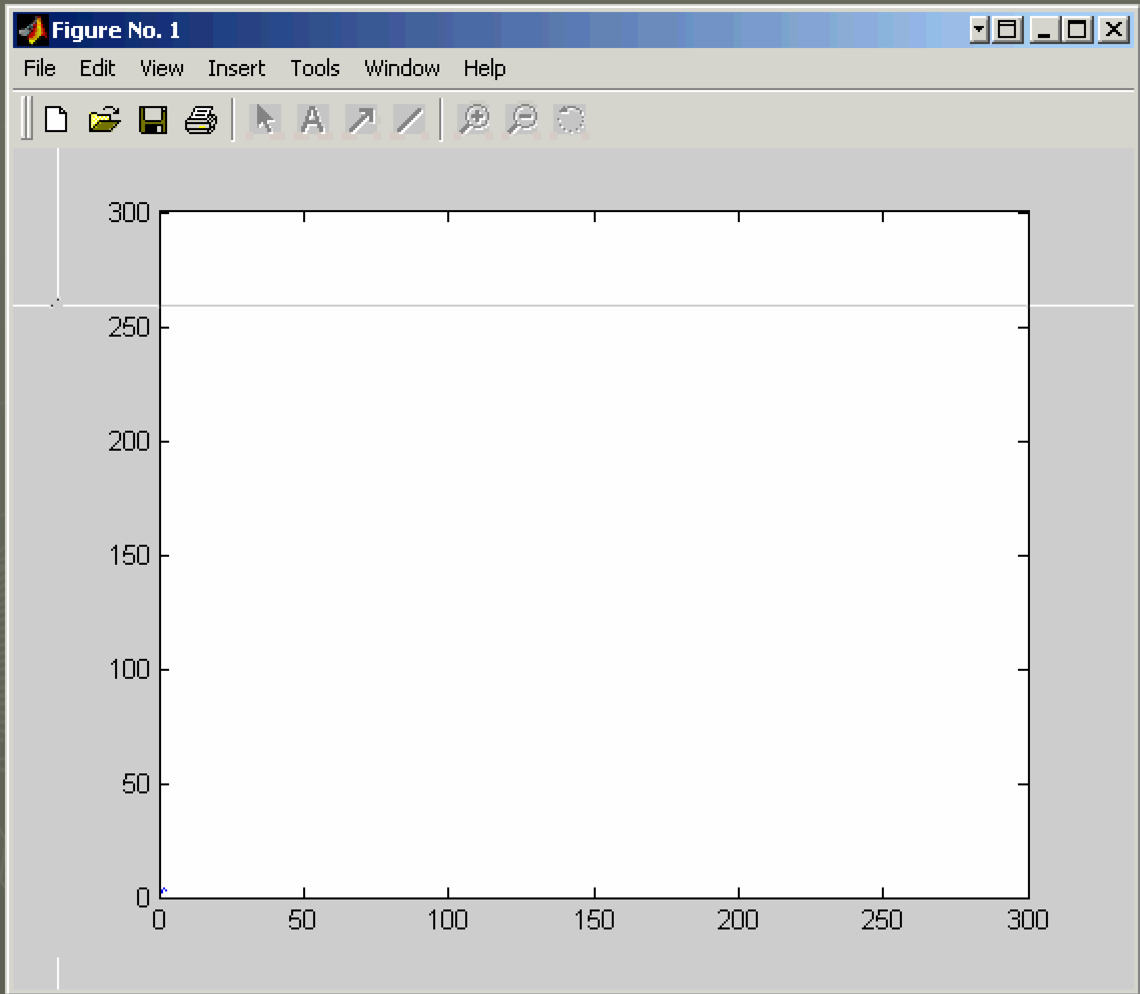
Priority Queue

Intersection Pts	V_a	V_b	e_a	e_b
I_i	V_i	V_{i+1}	e_{i-1}	e_{i+1}
.	.			
I_{i+2}	V_{i+2}	V_{i+3}	e_{i+1}	e_{i+3}

Output Skeleton

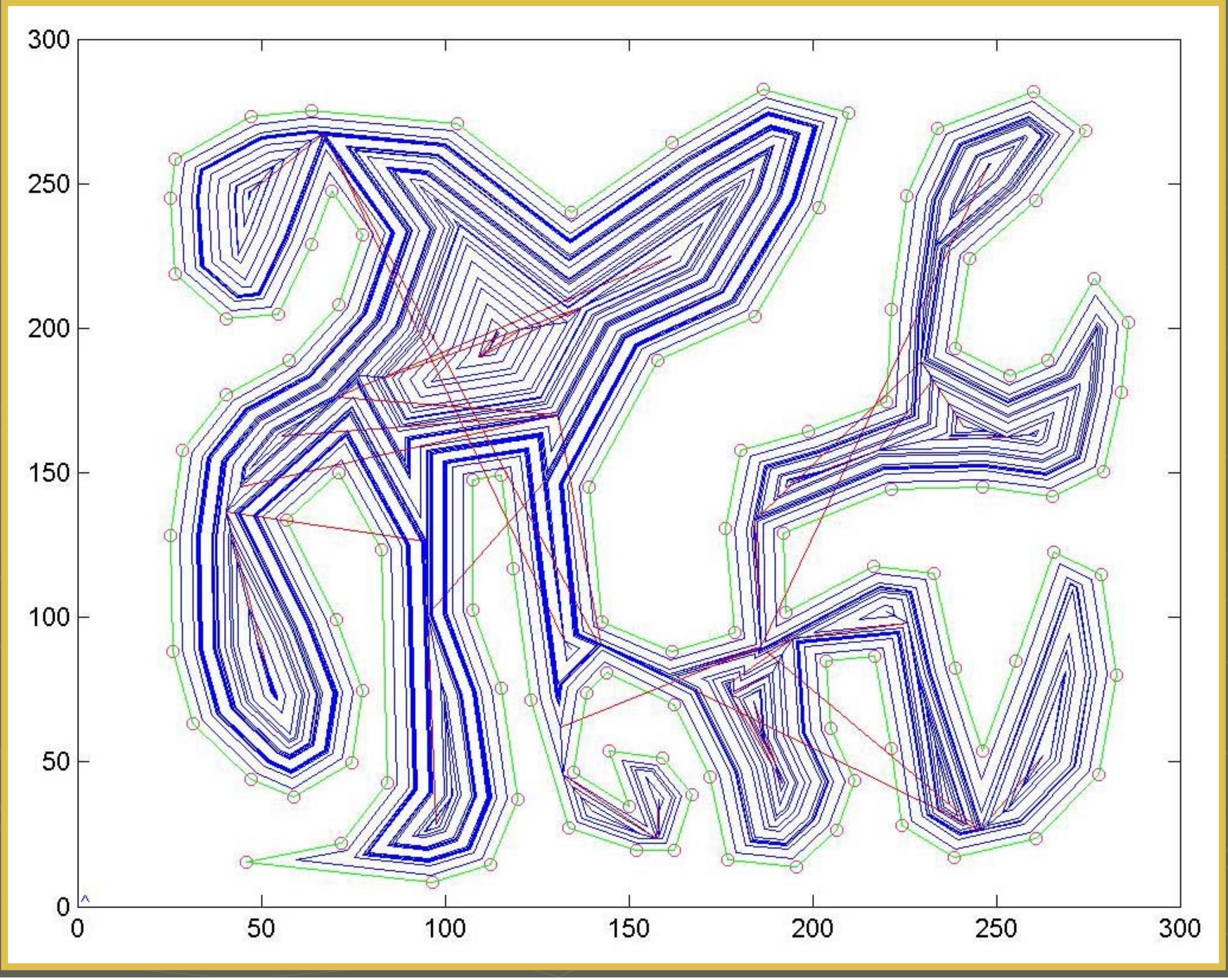
$V_a I$, $V_b I$

Sub-Module: Path Planning (2) ABNO



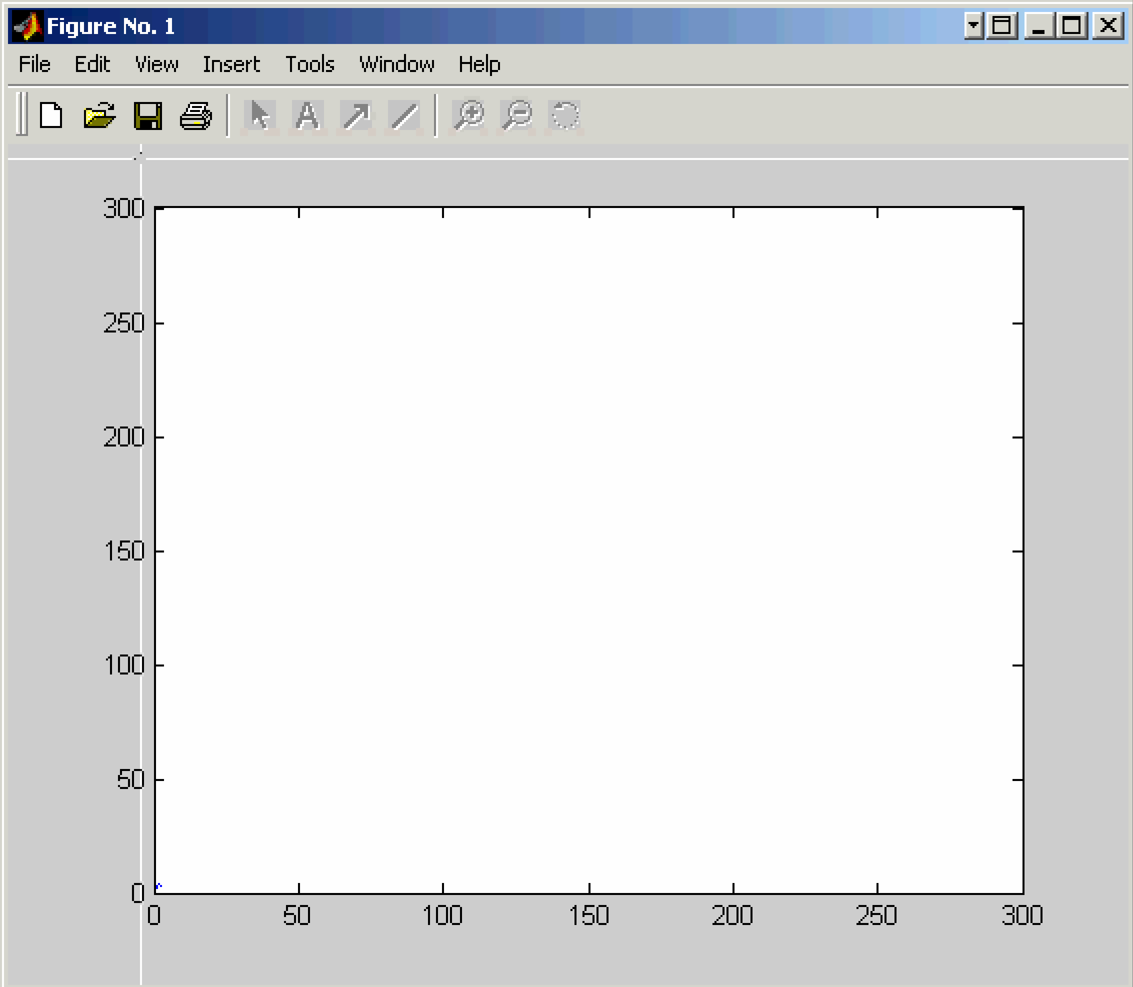
Sub-Module: Path Planning (2)

ABNO

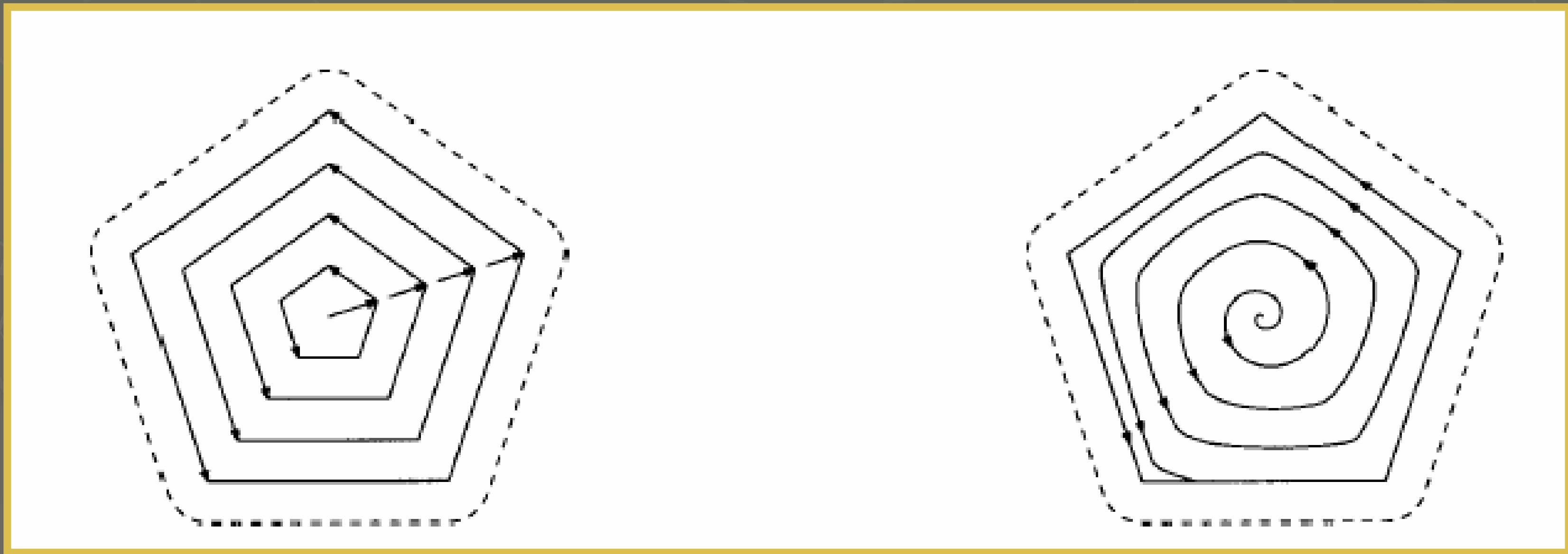


Sub-Module: Path Planning (2)

ABNO



Curvelinear Toolpaths



Current Status

- Grant from Biomedical Research Council of A-Star
- Ready for Animal/Cadaveric Clinical Trials
- Feasibility Studies to extend applications to Neuroendoscopy, Stereotactic Biopsy, Neuro-Osteotomies, Pedicle Screw Placements, Craniotomies, VP Shunt Insertions, maybe even stemcells implantation!

Current Members:

Principal Investigators: Dr. Ivan Ng & Charles Lo

Collaborators:

- Volume Interactions:
- Nanyang Technological University
- Singapore Institute of Manufacturing Technology

NATIONAL NEUROSCIENCE INSTITUTE

Thank You……..